

CLAIMS

We Claim:

- 5 1. A photoelectrode comprising:
a substrate that is transparent and insulating;
a front contact layer comprising a transparent conducting layer deposited on the
substrate as a front electrode (Electrode A) for a photovoltaic cell;
at least one of single-junction semiconductor pn or pin layers, or multiple-
10 junction stacked pin or pin layers, that generate photovoltage under illumination;
a back contact layer which is electrically conductive to form a back Electrode B,
which may be either a cathode or an anode but is opposite to the Electrode A;
an insulating layer that covers portions of the back contact layer;
a conducting layer that is electrically connected to the transparent conducting
15 layer (Electrode A), the conducting layer being either anode or cathode depending on the
polarity of the photovoltaic cell, but is opposite to Electrode B; and optionally
an oxygen evolution reaction layer; and further optionally, a hydrogen evolution
reaction layer, adapted to cover all or portions of the anode and the cathode,
respectively, and to protect the photovoltaic cell from chemical and electrochemical
20 corrosion.

2. The photoelectrode of claim 1, wherein at least one of the transparent
conducting layer, photovoltaic layers, and the back contact layer are electrically
separated into smaller area subcells, with each subcell or a combination of subcells
25 containing both an anode and a cathode so that the photoelectrode is functionally
separated into a multiple of sub-photoelectrodes.

3. The photoelectrode of claim 2, wherein the subcells are separated by
scribe lines.

4. The photoelectrode of claim 3 where in the scribe lines are at least one of laser scribed lines, mechanical scribed lines, or chemical scribed lines by screen-printing of chemical etching paste.
5. The photoelectrode of claim 3, comprising:
 - a first scribing adapted to remove predetermined portions of the front contact layer from the insulating substrates of at least one strip cell, thus electrically isolating the front contact layer into subcells;
 - a second scribing adapted to remove predetermined portions of at least one thin-film semiconductor layer;
 - a third scribing adapted to remove predetermined portions of the back metal contact layer from the semiconductor layers;
 - the first, second and third scribings adapted to being scribed adjacent to one another, thereby connecting the front contact layer of one strip cell with the back contact of a neighboring strip cell;
 - a fourth scribing adapted to remove predetermined portions of the back metal contact from the thin-film semiconductor layers, approximately at or near the position of the first scribe line, such that a small segment between the third and fourth scribe lines is electrically connected to the front electrode (Electrode A) and is electrically isolated from rest of the back contact (Electrode B); and
 - optionally, at least one catalyst layer for electrolysis adapted to be electrically connected with selected areas of the anode or cathode.
6. The photoelectrode of claim 5, wherein:
 - 25 the photovoltaic cell comprises solar cells that do not generate sufficient voltage for water electrolysis under illumination,
 - 30 the fourth scribing is adapted to be applied to at least certain subcells, the fourth scribing being adapted to connect at least two subcells into a unit cell, which, with added voltage from a multiple of subcells connected together, has voltage sufficient to drive water electrolysis;

an appropriate insulating layer covering predetermined areas of the back contact so that surfaces not resistant to corrosion are protected; and

wherein the conducting layer, electrically connected to front electrode (Electrode A) via the segment between the third and fourth scribes, is deposited at predetermined areas on top of the insulating layer.

7. The photoelectrode of claim 6, wherein the solar cells comprise at least one of single-junction solar cell or low-voltage double-junction solar cells.

10 8. The photoelectrode of claim 7, wherein the photovoltaic cell comprises at least one of:

single-junction thin-film silicon based solar cells,
single-junction (SJ) polycrystalline solar cells; or
double-junction solar cells.

15 9. The photoelectrode of claim 8, wherein the single-junction thin-film silicon based solar cells comprises at least one of single-junction (SJ) amorphous silicon (a-Si), SJ amorphous silicon germanium (a-SiGe), SJ microcrystalline silicon (mx-Si), SJ nanocrystalline silicon (nc-Si).

20 10. The photoelectrode of claim 8, wherein single-junction (SJ) polycrystalline solar cells comprises at least one of SJ cadmium telluride based solar cells, SJ CuInSe₂ based solar cells, SJ CuInGaSe₂ based solar cells.

25 11. The photoelectrode of claim 8, wherein the double-junction solar cells comprises at least one of a-Si, a-SiGe, mx-Si, nc-Si, CdTe, CuInSe₂, and CuInGaSe₂ based solar cells.

12. The photoelectrode of claim 5, wherein:

the photovoltaic cells comprise solar cells that do generate sufficient voltage for water electrolysis under illumination,

the fourth scribing is applied for every subcell,

an appropriate insulating layer covers predetermined areas of the back contact so
5 that surfaces not resistant to corrosion are protected, and

the conducting layer, electrically connected to front electrode (Electrode A) via the segment between the third and fourth scribes, is deposited at predetermined areas on top of the insulating layer.

10 13. The photoelectrode of claim 12, wherein the solar cells comprise at least one of triple-junction solar cells or high-voltage double-junction solar cells.

14. The photoelectrode of claim 13, wherein the photovoltaic cell comprises at least one of :

15 a double-junction solar cell comprising one or two of a-Si, a-SiGe, mx-Si, nc-Si, CdTe, CuInSe₂, and CuInGaSe₂ based solar cells;

a triple-junction solar cell comprising one or more of a-Si, a-SiGe, mx-Si, nc-Si, CdTe, CuInSe₂, and CuInGaSe₂ based solar cells, or

20 a quadruple-junction solar cell comprising one or more of a-Si, a-SiGe, mx-Si, nc-Si, CdTe, CuInSe₂, and CuInGaSe₂ based solar cells.

15. The photoelectrode of claim 5, wherein the anode or cathode, or both, are adapted to extend beyond a surface of the photovoltaic cell and back contact layer.

25 16. The photoelectrode of claim 15, wherein the front electrode (Electrode A) is electrically connected to a separate conducting layer which is not in contact with the Electrode B, via a segment between the third and fourth scribes.

17. The photoelectrode of claim 16, wherein:

the photovoltaic cells comprise solar cells that do generate sufficient voltage for water electrolysis under illumination,

the fourth scribing is adapted to be applied to every subcell,

appropriate insulating material covers exposed areas due to the third and fourth

5 scribes to prevent these areas from corrosion by electrolyte, and

the conducting layer, electrically connected to the front electrode (Electrode A) via the segment between the third and fourth scribes, is deposited on a separate plate such as a bottom plate of a photoelectrochemical cell, and

an electrical connector that electrically connects Electrode A and a separate plate

10 is covered by a corrosion-resistant insulating layer.

18. The photoelectrode of claim 17, wherein the solar cells comprises at least one of triple-junction solar cells or high-voltage double-junction solar cells.

15 19. The photoelectrode of claim 18, wherein the photovoltaic cell comprises at least one of:

a double-junction solar cell comprising one or two of a-Si, a-SiGe, mx-Si, nc-Si, CdTe, CuInSe₂, and CuInGaSe₂ based solar cells;

a triple-junction solar cell comprising one or more of a-Si, a-SiGe, mx-Si, nc-Si,

20 CdTe, CuInSe₂, and CuInGaSe₂ based solar cells; or

a quadruple-junction solar cell comprising one or more of a-Si, a-SiGe, mx-Si, nc-Si, CdTe, CuInSe₂, and CuInGaSe₂ based solar cells.

25 20. A method of making a photoelectrode comprising:

selecting a substrate that is transparent and insulating;

forming a transparent conducting layer on the substrate as a front electrode

(Electrode A) for a photovoltaic cell;

forming at least one of single-junction semiconductor pn or pin layers, or

multiple-junction stacked pin or pin layers, that generate photovoltage under

30 illumination;

forming a back contact layer which is electrically conductive to form a back contact (Electrode B), which may be either cathode or anode but is opposite to Electrode A;

5 forming an insulating layer that covers portions of the back contact (Electrode B);

forming a conducting layer that is electrically connected to the transparent conducting layer (Electrode A), the conducting layer being either anode or cathode depending on the polarity of the photovoltaic cell, but being opposite to Electrode B; and, optionally,

10 forming an oxygen evolution reaction layer and an hydrogen evolution reaction layer to cover all or portions of the anode and the cathode, respectively, and to protect the photovoltaic cell from chemical and electrochemical corrosion.

21. The method of claim 20, wherein at least one of the transparent conducting layer, photovoltaic layers, and the back-contact layer are electrically 15 separated into smaller-area subcells with each subcell group containing both anode and cathode, so that the photoelectrode is functionally separated into a multiple of subphotoelectrodes.

22. The method of claim 21, wherein the subcells are separated by scribe 20 lines.

23. The method of claim 22, wherein the scribe lines are formed by at least one of laser scribing, mechanical scribing, or chemical scribing by screen-printing of chemical etching paste.

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24. The method of claim 22, comprising:

conducting a first scribing which removes predetermined portions of the front contact layer from the insulating substrate, thus electrically isolating the front contact layer into subcells;

conducting a second scribing which removes predetermined portions of the thin-film semiconductor layers;

conducting a third scribing which removes predetermined portions of the back metal contact layer from the semiconductor layers;

5 the first, second and third scribing being scribed adjacent to one another, thereby connecting the front contact layer of one strip cell with the back contact of a neighboring strip cell;

conducting a fourth scribing, which removes predetermined portions of the back metal contact from the thin-film semiconductor layers approximately at or near the

10 position of the first scribe line, such that a segment between the third and fourth scribe lines is electrically connected to the front electrode (Electrode A) and is electrically isolated from rest of the back contact (Electrode B); and, optionally

15 forming at least one catalyst layer for electrolysis which is applied onto, or electrically connected with, selected areas of the anode or the cathode.

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25. A method of claim 24, wherein:

the photovoltaic cells comprises solar cells that do not generate sufficient voltage for water electrolysis under illumination,

20 the fourth scribing is applied for at least certain subcells, connecting at least two subcells into a unit cell, which, with added voltage from a multiple of subcells connected together, has voltage sufficient to drive water electrolysis; and

25 covering predetermined areas of the back contact with an insulating layer so that surfaces not resistant to corrosion are protected.

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26. The method of 25, wherein the solar cells comprise at least one of single-junction solar cell or low-voltage double-junction solar cells.

27. The method of claim 26, wherein the photovoltaic cell comprises at least one of:

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single-junction thin-film silicon based solar cells;

single-junction (SJ) polycrystalline solar cells; or
double-junction solar cells.

28. The method of claim 27, wherein the single-junction thin-film silicon
5 based solar cells comprise at least one of single-junction (SJ) amorphous silicon (a-Si),
SJ amorphous silicon germanium (a-SiGe), SJ microcrystalline silicon (mx-Si), SJ
nanocrystalline silicon (nc-Si).

29. The method of claim 27, wherein the single-junction (SJ) polycrystalline
10 solar cells comprise at least one of SJ cadmium telluride based solar cells, SJ CuInSe₂
based solar cells, SJ CuInGaSe₂ based solar cells.

30. The method of claim 27, wherein the double-junction solar cells comprise
at least one or two of a-Si, a-SiGe, mx-Si, nc-Si, CdTe, CuInSe₂, and CuInGaSe₂ based
15 solar cells.

31. The method of claim 24, wherein:
the photovoltaic cells comprise solar cells that do generate sufficient voltage for
water electrolysis under illumination,
20 the fourth scribing is applied for every subcell, and
an appropriate insulating layer covers predetermined areas of the back contact so
that surfaces not resistant to corrosion are protected.

32. The method of claim 31, wherein the solar cells comprise at least one of
25 triple-junction solar cells or high-voltage double-junction solar cells.

33. The method of claim 32, wherein the photovoltaic cell comprises at least
one of:
a double-junction solar cell comprising one or two of a-Si, a-SiGe, mx-Si, nc-Si,
30 CdTe, CuInSe₂, and CuInGaSe₂ based solar cells;

a triple-junction solar cell comprising one or more of a-Si, a-SiGe, mx-Si, nc-Si, CdTe, CuInSe₂, and CuInGaSe₂ based solar cells, or

a quadruple-junction solar cell comprising one or more of a-Si, a-SiGe, mx-Si, nc-Si, CdTe, CuInSe₂, and CuInGaSe₂ based solar cells.

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34. The method of claim 33, wherein the multiple-junction thin-film silicon based solar cells comprise a double-junction solar cell comprising one or two of a-Si, a-SiGe, mx-Si, nc-Si, CdTe, CuInSe₂, and CuInGaSe₂ based solar cells;

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35. The method of claim 33, wherein the multiple-junction solar cells comprise a triple-junction solar cell comprising one or more of a-Si, a-SiGe, mx-Si, nc-Si, CdTe, CuInSe₂, and CuInGaSe₂ based solar cells.

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36. The method of claim 33, wherein the multiple-junction solar cells comprise a quadruple-junction solar cell comprising one or more of a-Si, a-SiGe, mx-Si, nc-Si, CdTe, CuInSe₂, and CuInGaSe₂ based solar cells.

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37. A photoelectrochemical cell comprising
a photoelectrode,
an electrolyte, either alkaline or acidic, with which both anode and cathode are in contact;

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compartments for oxidation reaction where oxygen is generated;
compartments for reduction reaction where hydrogen is generated;
ion conduction layers placed between a oxidation compartment and a reduction compartment; and
an enclosure that confines the electrolyte for electrolysis.

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38. A method that uses the photoelectrochemical cell of claim 37 to produce hydrogen under radiation from the sun.